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INVENTOR(S): CHARLES B. MATTAS
OSCAR J. DEURLOO
VINCENT J. DELIA

TITLE: METHOD OF REGULATING POWER IN A HIGH-INTENSITY-DISCHARGE LAMP

ATTORNEYS: ROBERT J. KRAUS
PHILIPS ELECTRONICS
NORTH AMERICA CORPORATION
1251 AVENUE OF THE AMERICAS
NEW YORK, NEW YORK 10020
(914) 333-9634

METHOD OF REGULATING POWER IN A HIGH-INTENSITY-DISCHARGE LAMP

TECHNICAL FIELD

The invention relates to ballast circuits for operating high-intensity-discharge lamps and in particular to a novel ballast circuit to regulate lamp power over a wide range of supply and lamp voltages.

BACKGROUND OF THE INVENTION

High-intensity-discharge lamps consist of tubes in which electric arcs in a variety of materials are produced. An outer glass envelope provides thermal insulation in order to maintain the arc tube temperature. The temperature of the arc tube influences the color of the light produced and the life expectancy of the lamp. A ballast circuit is used to provide a high voltage to initiate an arc in the arc tube and supply power to maintain the arc. By regulating the power supplied to the lamp, the arc tube temperature can be controlled. Examples of high-intensity-discharge lamps include metal halide and high-pressure sodium-vapor lamps. Recent advances in high-intensity-discharge lamps have improved the color, start up time, and life expectancy opening doors to new markets previously dominated by incandescent lamps. One draw back of the new high-intensity-discharge lamps is that the new lamps require tighter power supply regulation.

A typical high-intensity-discharge ballast circuit is shown in FIG 1. The circuit consists of an inductor 250 in series with the lamp 256 and a capacitor 254 shunting the voltage supply 252 for power factor correcting. The inductor is typically sized to provide optimal power to a nominal lamp at a given supply voltage. The power supplied to the lamp (P_{lamp}) will be the voltage across the lamp (V_{lamp}) multiplied by the current through the lamp (I_{lamp}). Appling Ohms law, I_{lamp} equals V_{lamp} divided by the lamp resistance (R_{lamp}). Summing the voltages around the circuit, supply voltage (V_{supply}) will equal the voltage across the

inductor ($V_{inductor}$) plus V_{lamp}. Rewriting the power equation yields $P_{lamp} = (V_{supply} - V_{inductor})^2 / R_{lamp}$. As the lamp ages, it's resistance may decrease. Many utility companies consider variations in supply voltage up to ten percent from nominal typical and acceptable. Changing loads on the power supply may cause the voltage to vary more than the typical ten percent in some applications. As shown in the above lamp power equation, variations in lamp resistance and supply voltage can cause the power supplied to the lamp to vary. In many lighting applications, it is desirable to have a lamp emitting a constant light intensity, which requires providing constant power to the lamp. In addition to providing consistent light intensity, a constant power supply may increase the life of the lamp. In other applications it may be desired to operate the lamp at various constant power levels to dim, reduce power consumption, or change the color of the lamp.

Electronic ballasts are available today, which provide constant power and dimming capabilities. However, these ballasts are much more expensive. The increased expense may be due to the additional circuitry required to sense, calculate, and regulate the power supplied to the lamp. Of the three circuits, the one used to calculate the power in the lamp is usually most expensive. As noted above, the power supplied to a lamp may be calculated by multiplying the voltage across the lamp times the current passing through the lamp. Circuits to multiply generally are complicated and require a high level of precision accounting for the high cost.

What is therefore needed is a ballast circuit that will provide constant power utilizing an inexpensive power regulating circuit, and provide for optional dimming of the lamp.

SUMMARY OF THE INVENTION

One aspect of the invention provides a method of controlling power to a high-intensity-discharge lamp. Voltage across and current through the lamp are determined. Power to the lamp may be approximated using the voltage and current. Power to the lamp can be regulated based on a comparison of the approximated power and a predetermined value.

Current through the lamp is determined by converting the current to a representative voltage. The voltage across the lamp is determined by scaling the lamp voltage. Lamp power is approximated by the summation of the representative voltage and the scaled voltage. A comparison is made whether the approximated power is greater or less than the predetermined value.

Another aspect of the invention provides a system of controlling power to a high-intensity-discharge lamp. Voltage across the lamp is determined by a voltage sensor. Current through the lamp is determined by a current sensor. A control circuit is operatively connected to the current sensor and voltage sensor. The control circuit approximates a lamp power based on input from the sensors. The control circuit compares the lamp power against a desired level and regulates lamp power based on the comparison. The current sensor comprises a resistor connected in series with the lamp. A signal conditioning circuit scales and filters the output of the current sensor. The voltage sensor comprises a voltage divider network shunting the lamp. The voltage divider includes a voltage-limiting network. The control circuit includes a summing circuit. The summation circuit includes a filter and a plurality of rectifiers. The control circuit includes a voltage reference signal generator. The signal generator produces a saw tooth waveform synchronized with the sensed current and twice the frequency of the sensed current. The control circuit includes a current limiting component. The control circuit includes a comparator circuit.

The foregoing and other features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiments, read in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is prior art showing a schematic view of a typical magnetic ballast;

FIG. 2 is a partially schematic, partially block diagram of one embodiment of a high-intensity-discharge lamp ballast circuit with power regulation;

FIG. 3 shows a timing diagram of waveforms in the ballast circuit of **FIG. 2**; and

FIG. 4 shows a plot of true constant power and a linear function approximating true power.

DETAILED DESCRIPTION OF THE
PRESENTLY PREFERRED EMBODIMENTS

One embodiment of a ballast circuit to regulate lamp power is illustrated in **FIG. 2** designated in the aggregate as numeral **10**. The ballast circuit may include sensors to allow determining voltage across and current through the lamp and a control circuit that calculates lamp power using information from the sensors, compares the lamp power against a desired level, and regulates lamp power based on the comparison.

A sensor may sense the current through a lamp. In one embodiment, the current sensor may comprise a resistor **40** connected in series with the lamp **50**. One side of the resistor **40** may be connected to a terminal **48** to which the neutral of an AC voltage supply **52** may be connected. The other side of the resistor may be connected to a signal conditioner circuit **130**, resistor **38** and zener diode **44** of the voltage sensing network **54**, and a terminal **46** to which one side of the lamp **50** may be connected. Those skilled in the art will recognize that the resistor **40** may be replaced with a network of resistors to obtain a desired resistance and power dissipation.

A sensor may sense the voltage across the lamp. In one embodiment, the voltage sensor **54** may comprise three resistors **34**, **36**, and **38** connected in series to form a voltage divider. Resistors **36** and **38** may be shunted by two zener diodes **42** and **44** connected in series anode to anode. The zener diodes **42** and **44** may be selected to limit the voltage across resistors **36** and **38**. Limiting the voltage can reduce the starting voltage component of the voltage sensor output waveform. By reducing the starting voltage component, a more accurate representation of lamp voltage may be obtained. Resistor **34** may be connected to a terminal **32** to which the other side of the lamp **50** and an inductor **30** may be attached. Resistors **38** and **36** may connect to one input of the summation circuit **120**.

The ballast circuit may include a control circuit that calculates lamp power using information from the sensors, compares the lamp power against a desired level, and regulates lamp power based on the comparison. In one embodiment, the control circuit may comprise a signal conditioner **130**, summation circuit **120**, comparator **110**, reference generator **100**, and current limiting circuit **56** controlled by the comparator.

A signal conditioner circuit may be connected to the output of the current sensor to condition the signal for processing. In one embodiment, the signal conditioner **130** may amplify the voltage across the current sensing resistor **40**. Those skilled in the art will recognize the need for such amplification as the output voltage of the current sensor of the type described above is usually kept low for power considerations.

A summation circuit may be used to calculate the approximate power by adding the voltages representing lamp voltage and current. The summation circuit **120** may add the absolute value of the voltages from the signal conditioner **130** and voltage sensor **54**. The summation circuit **120** may include a filter to average the sum of the two voltages over time. True lamp power may be calculated by multiplying lamp current and lamp voltage. **FIG. 4**. shows a plot of true constant lamp power over a range of lamp voltages and currents. A linear function of current and voltage, also plotted in **FIG. 4**, may be found that

approximates true constant lamp power over a range of lamp voltages and currents. The equation for the linear function may be expressed by the equation, $K = A(V_{lamp}) + B(I_{lamp})$. Whereas, I_{lamp} is the lamp current, V_{lamp} is the lamp voltage, and K, A, and B are constants. The linear equation and **FIG. 4** show that an approximate lamp power may be calculated by summing scaled lamp voltage and current.

A reference generator may be used to generate a reference voltage for comparing to the voltage representing approximant power. In one embodiment, the reference generator **100** may produce a saw tooth waveform synchronized to the supply voltage waveform. The saw tooth waveform may be of a frequency twice that of the supply voltage. The amplitude of the saw tooth waveform may increase with time to a desired level then reset.

A comparator circuit may compare the power level of the lamp to a desired level and output a signal based on the comparison. In one embodiment, the comparator **110** may compare the voltage level representing approximant actual power to the reference waveform. The comparator **110** may have an electrically isolated output. The comparator **110** may have a reset function limiting the active pulse width to a desired duration. Those skilled in the art will recognize comparing a low voltage from the summation circuit **120**, indicating power to the lamp is low, to an increasing saw tooth waveform may result in an output signal becoming active sooner than the output signal when a higher voltage from the summation circuit **120** is compared. They will also recognize that this type of signal may be used to control the conduction angle of a triac, insulated gate bipolar transistor (IGBT), silicon controlled rectifier (SCR), or other electronic switch.

An electronic switch may shunt a load-limiting device to control the power to a lamp. In one embodiment, the current limiting portion **56** of the control circuit may include an inductor **20** connected in parallel to an inductor **16** in series with a triac **26** through terminals **18** and **28**. The gate of the triac **26** may be connected to the output of the comparator circuit **110**. The triac **26** may be shunted by a snubbing circuit comprised of resistor **22** and capacitor **24**

connected in series. The inductors **16** and **20** may be connected to a fuse **14**. The other side of the fuse **14** may be connected to a terminal **12** to which the line side of a voltage supply **52** may be connected. Those skilled in the art will recognize when the triac **26** is not conducting, inductors **20** and **30** may limit the power to the lamp **40**. When the triac **26** is conducting, inductor **30** and the effective inductance of inductors **16** and **20** in parallel may limit the power in the lamp **40**. If the conduction angle of the triac is varied, any average power level between the two said levels may be achieved. They will also recognize that inductor **20** may be replaced with a resistor, a resistor in series with a capacitor, or other current limiting device.

In operation, the ballast circuit may sense voltage across and current through the lamp, calculate lamp power using information from the sensors, compare the lamp power against a desired level, and regulate lamp power based on the comparison.

Fig. 3 shows a timing diagram for waveforms in one embodiment of the ballast circuit **10**. Diagram 1 shows the voltage waveform of the power supply **52**. Diagram 2 shows the voltage waveform of the lamp **50**. Diagram 3 shows the current waveform of the lamp **50**. Diagram 4 shows the voltage waveform at the output of the voltage sensor **54**. Diagram 5 shows the voltage waveform of the signal conditioner **130** output. Diagram 6 shows the waveforms of the reference generator **100** and the output of the summation circuit **130**. Diagram 7 shows the output signal of the comparator **110**.

During the time from t1 to t2, the arc in the lamp may be extinguished. When there is no arc in the lamp, any current flow through the lamp **50** and resistor **40** may be negligible. If no current is passing through resistor **40,** no voltage may be developed across the resistor **40** or the input of the signal conditioner. With no voltage applied to the input of the signal conditioner **130**, the output of the signal conditioner **130** may be zero. If no current is flowing through the lamp **50**, the lamp voltage can equal the supply voltage. The voltage across the lamp **50** may be divided by resistors **34**, **36**, and **38** resulting in a scaled lamp voltage being applied to the summation circuit **120**. If the sum of the

absolute value of the inputs to the summation circuit **120** is less than the output of the summation circuit **120**, the output voltage of the summation circuit **120** may decrease slightly.

At the time t2, the voltage across the lamp **50** may increase to a level triggering the starter circuit **140** to apply a high voltage across the lamp **50**. The high voltage from the starter circuit **140** may initiate an arc in the lamp **50**. As the starter voltage is divided by the resistors **34**,**26**, and **38**, the voltage across resistors **36** and **38** may increase. When the voltage across resistors **36** and **38** increases to the zener voltage of the zener diodes **42** and **44**, the diodes may start conducting limiting the voltage to the input of the summation circuit **130**.

During the time between t2 and t3, an arc may be present in the lamp **50** allowing current to flow through the lamp **50**, resistor **40**, and inductors **20** and **30**. The current through resistor **40** may produce voltage across resistor **40**. The signal conditioner **130** may amplify the voltage across resistor **40** and output a voltage to the summation circuit **120** representative of the lamp current. The voltage of lamp **50** may be equal to the supply voltage less the voltage drop across inductors **20** and **30**. The lamp voltage may be scaled by the voltage divider resulting in a scaled voltage to the input of the summation circuit **120**.

At the time t3, the voltage from the reference generator **100** may exceed the output voltage from the summation circuit **120**. When the voltage from the reference generator **100** first exceeds the summation circuit **120** output voltage, the comparator **110** may output a pulse to the gate of the triac **26** causing the triac **26** to conduct. Once the triac **26** conducts, it will remain in the conducting state until the current passing through the triac **26** goes to zero even if the voltage to the gate is removed. When the triac **26** is conducting, the lamp voltage and current may increase due to the reduced inductance of inductor **16** in parallel with inductor **20**.

At the time t4, the lamp voltage and current pass through zero resetting the reference generator **100**. When there is no current through the triac, the triac will go into a non-conducting state. When there is no lamp voltage, the arc will extinguish. Those skilled in the art will recognize that the control circuit is bipolar and the above operation will repeat on the negative portion of the supply voltage.

While the embodiments of the invention disclosed herein are presently considered preferred, various changes and modifications can be made without departing from the spirit and scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.